

**TEMPERATURE CONTROL APPARATUS AND METHOD
FOR HIGH ENERGY ELECTROCHEMICAL CELLS**

Field Of The Invention

15 The present invention relates generally to energy storage devices and, more particularly, to apparatuses and methods for controlling the temperature of high energy electrochemical cells during operation.

Background Of The Invention

20 The demand for new and improved electro-mechanical systems, such as hybrid electric vehicles for example, has placed increased pressure on the manufacturers of energy storing devices to develop battery technologies that provide for high energy generation in a low-volume package. A number of advanced battery technologies have recently been developed, such as metal hydride (e.g., Ni-MH), lithium-ion, and lithium polymer cell technologies, which would appear to provide the requisite level of energy
25 production and safety margins for many commercial and consumer applications. Such advanced battery technologies, however, typically exhibit characteristics that provide challenges for the manufacturers of advanced energy storage devices.

30 For example, advanced power generating systems typically produce a significant amount of heat which, if not properly dissipated, can result in non-optimal performance of the system. Moreover, poor thermal management of such cells can result in a thermal

DE 19849491 relates to an electrochemical energy storage unit having several feed and return channels connected by heat exchange channels through which heat exchange medium passes in alternate directions. An electrochemical energy storage unit comprises one or more rows of adjacent storage cells associated with a heat exchange structure which has several feed and return channels arranged on its opposite sides and connected by heat exchange channels. Each heat exchange channel extends once across the storage cell arrangement and heat exchange medium passes through the heat exchange channels in alternate directions.

JP-A-07-073908 relates to a heat exchanger which is composed of plural batteries, a housing case having the housing chambers of the batteries, and heat-exchanging bags arranged in the middle to pass heat-exchanging fluid. The bags in the respective housing chambers are linked with each other by communication parts arranged in the grooves in the case, and the heat exchanging fluid flows through the respective bags. The heat-exchanging fluid is closely contacted with the battery and the case due to the internal pressure of the fluid to improve heat-exchanging efficiency.

WO0227816 relates to a multi-cell monoblock battery in which a plurality of electrochemical cells are disposed in a battery case. The battery case includes one or more cell partitions which divide the interior of the case into a plurality of cell compartments that house the electrochemical cells. Preferably, one or more coolant channels are integrally formed with at least one of the cell partitions. The coolant channels may have inlets and outlets disposed in the walls of the battery case so as to provide a cross-flow cooling design.

DE19503085 describes a battery module with several electrochemical storage accumulators (cells) and with the cells having electrically insulating units acting also as channels for a temperature control liquid, the unit is formed as a pouch, with internal temperature control units for a liquid coolant, closed hermetically from the inlet and outlet.

includes a number of flow channels within which the heat transfer medium passes. In general, the cooling bladder covers substantially all of the surface area of each of the cells.

According to one configuration, the cooling bladder includes a support arrangement that inhibits restriction of heat transfer medium flow at cooling bladder bend locations. The support arrangement can be located on an outer surface of the cooling bladder at cooling bladder bend locations. The support arrangement can also be located within the cooling bladder at cooling bladder bend locations. The support arrangement can further be integrated within the cooling bladder construction at cooling bladder bend locations.

For example, the cooling bladder may include a porous filler material disposed within the cooling bladder. The porous filler material can be disposed at cooling bladder locations subject to bending. In another approach, the cooling bladder includes thickened sections provided at cooling bladder locations subject to bending.

The cooling bladder can be designed to include an interior compartment within which the heat transfer medium passes between the inlet port and the outlet port in a unidirectional manner. The cooling bladder can also be designed to include a number of compartments through which the heat transfer medium passes. For example, the cooling bladder can include a first interior compartment and a second interior compartment. The transfer medium passing within the first interior compartment preferably flows in a direction opposing that of the transfer medium passing within the second interior compartment.

The cooling bladder can be constructed from a conformable thermally conductive material having a single material layer or from a conformable thermally conductive material having a number of material layers. For example, the conformable thermally conductive material can include a metallic layer disposed between a first polymer layer and a second polymer layer.

The cooling bladder's conformable thermally conductive material preferably has a thickness of less than about ^{3.8mm} (150 mils). Advantageously, the cooling bladder and the heat

31 are arranged on the cooling bladder 30 to provide for side access through adjacent side walls of the housing body 22.

The housing body 22 is fabricated to include channels 19 and 17 that respectively accommodate outlet and ports 33 and 31 as the cell stack assembly 28 and cooling bladder 30 are installed into the housing body 22. An outlet aperture 36 and an inlet aperture 34 are provided in side walls of the housing body 22 to permit external connection to respective outlet and inlet conduits. When the cell stack assembly 28 and cooling bladder 30 are properly installed in the housing body 22, the outlet and inlet ports 33, 31 register with the outlet and inlet apertures 36, 34 of the housing body 22. Outlet and inlet conduits, such as hoses or the like, may subsequently be connected to the outlet and inlet ports 33, 31. The inlet conduit provides a source supply of a heat transfer medium to the inlet port 31 of the cooling bladder 30, and the outlet conduit connected to the outlet port 33 provides a return path for the heat transfer medium after having passed through the cooling bladder 30.

According to this embodiment, the circuit board 42 is positioned on top of the cell stack assembly 28 adjacent the housing lid 32. The circuit board 42 includes a number of leads 51 to which a corresponding number of tabs 53 are attached. The tabs 53 extend from the leads 51 of the circuit board 42 and connect with tabs 74 of the cells 15 of the cell stack assembly 28. In a typical configuration, one of the circuit board tabs 51 provides electrical connection to one of the cell tabs 74. The cell leads 51 are preferably fabricated as copper bars and include a swaged flexible (e.g., braided) mid-section. The cell tabs 51 are preferably ultrasonically welded to the cell leads 51. The circuit board 42 may further include various electrical and/or electronic circuits 52, such as bypass circuitry, equalization circuitry, fuses, and the like.

In the embodiment depicted in Figs. 2 and 3, positive and negative terminals 41 and 43 are electrically connected to the leads 51 of the circuit board 42, typically through electrical/electronic circuitry 52. The terminals 41 and 43 respectively register with apertures 45 and 47 of the housing lid 32. As such, external electrical connections with the energy storage device 40 are established through the top housing lid 32 of the energy

Lithium polymer batteries employ a solid polymer electrolyte as an alternative to the liquid electrolytes of lithium ion batteries. These batteries have lower ionic conductivities as compared to lithium ion batteries and are thus usually operated at temperatures above ambient, such as 60-100°C. Lithium polymer batteries also offer advantages of a "non-liquid" battery and flexibility of configuration. The anodes of such batteries are lithium metal, electrolytes are typically crosslinked copolymers of polyethylenoxide, and cathodes are metal oxides, such as lithium vanadium oxide.

Lithium ion polymer gel batteries exhibit improved conductivity as compared with lithium polymer batteries by incorporating a plasticizer, such as propylene carbonate, into the solid polymer matrix. Lithium ion polymer gel batteries may be viewed as hybrids between the lithium ion and solid polymer batteries.

Nickel metal hydride batteries use hydrogen absorbed in a metal alloy in the form of a hydride for the active negative material. These alloys are typically rare earth (e.g., Misch metal) based on lanthanum nickel or alloys based on titanium zirconium. The active material of the positive electrode is nickel oxyhydroxide. The electrolyte is aqueous potassium hydroxide.

The electrochemical cells 15 employed in the cell stack assembly 28 depicted in the drawings are typically prismatic in configuration. The cells 15 generally have two opposing planar surfaces that account for most of the cell's surface area relative to edges of the cells. For example, a typical cell 15 may be fabricated to have a length of approximately 160 mm, a height of approximately 125 mm, and a thickness of only 9 mm. Another set of useful cell dimensions, ^(12.7 cm) ~~in terms of inches~~, includes a surface area of about ^(5 inches) ~~by (5 inches)~~ and a thickness of about ^(0.33 inches) ~~(0.33 inches)~~.

The electrochemical cells 15 subject to cooling in accordance with the principles of the present invention need not have a prismatic configuration. By way of example, the electrochemical cells 15 may have a cylindrical shape or have a multifaceted configuration (e.g., a hexagonal cross section). The electrochemical cells 15 can also have a rounded shape (e.g., an oval cross section).

anode and cathode material. This migration creates a corresponding increase and decrease in total cell volume on the order of approximately five to six percent during charging and discharging, respectively. Other types of advanced rechargeable batteries (e.g., lithium ion, lithium ion polymer, and nickel metal hydride) likewise exhibit significant increases and decrease in total cell volume during charge and discharge cycling.

It is understood that the performance and service-life of an electrochemical cell that undergoes repeated cycles of expansion and contraction is significantly increased by maintaining the layers/components of the cell in a state of compression. Improved cell performance may be realized by maintaining pressure on the two larger opposing surfaces of the cell during cell charge and discharge cycling. It is considered desirable that the compressive forces exerted on the cells be distributed fairly uniformly over the surface of application.

A cooling apparatus and methodology of the present invention provides the requisite level of temperature control needed to maximize the performance of advanced rechargeable cells and strings/stacks of such cells. Moreover, a cooling apparatus and methodology of the present invention provides the requisite level of pressure control at as the cells undergo net external volumetric changes during operation. For example, the cooling apparatus can produce pressures ranging between about (34 kPa) (5 psi) and about (414 kPa) (60 psi) as needed in a given application, it being understood that lower or higher pressures can be achieved if needed or desired. A cooling apparatus and methodology of the present invention provides a mechanism to maintain good thermal contact with the cells of the string/stack continuously and in the presence of significant cell volume changes during operation.

Returning to the figures, and more particularly to Figs. 4 and 5, there is illustrated two embodiments of a cooling apparatus well-suited for use with advanced rechargeable cells and batteries. The cooling bladder 30 is fabricated from a resilient material which is sealed along the periphery to form one or more hollowed interior compartments. External access to the interior compartment(s) is achieved through attachment to inlet and outlet ports 31, 33. The cooling bladder 30 may be fitted with a single pair or multiple pairs of

design of a given energy storage device that incorporates a cooling bladder 30 of the present invention.

For purposes of illustration and not of limitation, the cooling bladder 30 illustrated in Figs. 4 and 5 can be fabricated to have a length of several feet. For example, the length of the cooling bladder 30 can range between ^{1.5 and 3 m} (5 and 10 feet) for many applications (e.g., ^{12.1 m to 2.3 m} 7 feet to 7.5 feet). The cooling bladder 30 can have a width of several inches. For example, the cooling bladder 30 can have a width ranging between ^{10.2 and 17.8 cm} (4 and 7 inches). Generally, the width of the cooling bladder 30 is designed to accommodate the width of the electrochemical cells employed in a given energy storage device. The cooling bladder's conformable thermally conductive material 30 can have a thickness that ranges between ^{0.152 mm and 3.8 mm} (about 6 mils and 150 mils).

For example, an energy storage module may incorporate lithium ion prismatic cells having a width and height of about ^{12.7 cm} (5 inches) and a thickness of about ^{0.84 cm} (0.33 inches). An appropriate width of the cooling bladder 30 for such ^{12.7 cm x 12.7 cm} (5" x 5") cells can range between ^{12.7 cm and 15.2 cm} (5 inches and 6 inches), with ^{14 cm} (5.5 inches) being a suitable width. The length of the cooling bladder 30 is dependent on a number of factors, including the number of cells used in a cell stack assembly, the tolerance for temperature variations across a cell and the cell stack, and the number of cell stack assemblies used in a given energy storage module, for example.

By way of example, a particular energy storage module may incorporate four cell stack assemblies each of which incorporates 12 electrochemical cells having dimensions of ^{cm x 12.7 cm x 0.84 cm} about (5" x 5" x 0.33"). In such a configuration, one cooling bladder 30 can be employed to provide temperature control for a corresponding one of the four cell stack assemblies, for a total of four cooling bladders 30. Each of the cooling bladders 30 can have a length of ^{218.4 cm} about (7 feet-2 inches), and a width of about ^{14 cm} (5.5 inches).

One or more locations along the periphery of the cooling bladder 30 can be sealed to form the cooling bladder 30. For example, a ^{9.5 mm} (3/8 inch) wide seal can be used at two peripheral locations along the sides of the cooling bladder 30 to provide sealing along the length of the cooling bladder 30. A ^{1.27 cm} (1/2 inch) wide seal can be used at two peripheral

locations along the ends of the cooling bladder 30 to provide sealing along the opposing ends of the cooling bladder 30.

Figures 6 and 7 illustrate additional features of a cooling bladder 30 of the present invention. According to this illustration, the cooling bladder 30 includes an active region 37 and a sealed region 39. The active region 37 defines the unsealed portion of the cooling bladder 30 within which a heat transfer medium passes via inlet and outlet ports 31 and 33. The active region 37 thus represents the portion of the cooling bladder 30 that comes into thermal contact with the electrochemical cells and provides the requisite temperature control for the cells. As such, the width of the active region 37 of the cooling bladder 30 is designed to accommodate the width of the active region of the subject cells. The inactive sealed region 39 is shown to have a width that exceeds the width of the subject cells.

By way of example, and assuming use of $(12.7\text{ cm} \times 12.7\text{ cm})$ cells that have an active area of $(10.8\text{ cm} \times 10.8\text{ cm})$ about $(4.25'' \times 4.25'')$ the active region 37 of the cooling bladder 30 can have a width of (11 cm) about $(4.33'')$. The sealed region 39 can extend beyond the active region 37 by about (4.6 cm) about $(1.8'')$, such that the total width of the cooling bladder (width of active region 37 plus width of inactive region 39) is about (15.7 cm) about (6.2 inches) in this illustrative, non-limiting example.

The active region 37 of the cooling bladder is generally designed to manage a maximum allowable amount of heat that is generated by a grouping of electrochemical cells during operation. The maximum allowable heat limit typically takes into account the excess heat generated during a short circuit event within a cell string, and also varies depending on the availability of bypass circuitry or other short circuit control devices that limit the amount of heat generated by a short circuited cell or cells. For example, a string of 12 cells may require that the cooling bladder 30 manage 18 W of heat dissipation per cell during normal operation. In this illustrative example, the cooling bladder 30 is to be designed to manage about 220 watts (i.e., $Q = 220\text{ W}$) of heat dissipation from the string of 12 cells ($12\text{ cells} \times 18\text{ W/cell} = 216\text{ W}$).

The heat transfer medium passing through the cooling bladder 30 is typically water or a combination of an anti-freeze and water (e.g., a blend of water and ethylene glycol or a mixture of methanol and ethylene glycol). The rate of heat transfer medium flow

In another configuration, support for the cooling bladder structure can be provided by an arrangement external to the cooling bladder 30, such as by use of a sleeve 63 of a resilient reinforcing material attached to the exterior surface of the cooling bladder 30, as is shown in Fig. 8. Also, portions of the cooling bladder 30 designed to bend for a given application can be thickened relative to other portions of the cooling bladder 30 as part of cooling bladder fabrication.

As was discussed previously, the cooling bladder or bladders used within an energy storage device may provide for serial or parallel flows. Figures 11A and 11B illustrate an embodiment in which a cooling bladder 30 is integrated within a cell stack assembly 28 to provide for serial coolant flow through the cooling bladder 30. Figures 11A and 11B show a string of electrochemical cells 15 arranged in a spaced apart relationship to form the cell stack assembly 28. The cooling bladder 30 is assembled in a "fan-folded" fashion such that the active region 37 of the cooling bladder 30 contacts the active heat producing region of the cells 15. As shown, the cooling bladder 30 takes on a serpentine shape when it is installed within the cell stack assembly 28.

When the sub-assembly of the cell stack assembly 28 fitted with the cooling bladder 30 is properly installed within an energy storage module housing, electrical connections between cell tabs 74 and tabs of a circuit board or interconnect board are properly established. The inlet and outlet ports 31, 33 are respectively connected to supply and return lines (not shown) of an external cooling system. During operation, a heat transfer medium passes through the inlet port 31, through the interior compartment of the cooling bladder 30, and passes out to the cooling bladder 30 via the outlet port 33 in a serial manner.

Figures 12A and 12B illustrate an embodiment in which a cooling bladder 30 is integrated within a cell stack assembly 28 to provide for multiple ^{parallel} ~~serial~~ coolant flow pathways. In the configuration depicted in Figs. 12A and 12B, a number of independent cooling bladders 30 are integrated within the string of electrochemical cells 15 of the cell stack assembly 28. As shown, each electrochemical cell 15 is sandwiched between two independent cooling bladders 30. It is noted that the inlet and outlet ports 31, 33 of the

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